IN-20
171954
P.18

NASA Technical Memorandum 105785

Small Stirling Dynamic Isotope Power System for Robotic Space Missions

D.J. Bents
Lewis Research Center
Cleveland, Ohio

Prepared for the
Nuclear Technologies for Space Exploration
sponsored by the American Nuclear Society
Jackson Hole, Wyoming, August 16–19, 1992

NASA

Small Stirling Dynamic Isotope Power System for Robotic Space Missions

D.J. Bents
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

Design of a multihundred-watt Dynamic Isotope Power System (DIPS) based on the U.S. Department of Energy (DOE) General Purpose Heat Source (GPHS) and small (multihundred-watt) free-piston Stirling engine (FPSE) is being pursued as a potential lower cost alternative to radioisotope thermoelectric generators (RTG's). The design is targeted at the power needs of future unmanned deep space and planetary surface exploration missions ranging from scientific probes to Space Exploration Initiative precursor missions.

Power level for these missions is less than a kilowatt. The incentive for any dynamic system is that it can save fuel, reducing cost and radiological hazard. Unlike DIPS based on turbomachinery conversion (e.g. Brayton), this small Stirling DIPS can be advantageously scaled to multihundred-watt unit size while preserving size and mass competitiveness with RTGs . Stirling conversion extends the competitive range for dynamic systems down to a few hundred watts -- a power level not previously considered for dynamic systems. The challenge for Stirling conversion will be to demonstrate reliability and life similar to RTG experience.

Since the competitive potential of FPSE as an isotope converter was first identified, work has focused on feasibility of directly integrating GPHS with the Stirling heater head. Thermal modeling of various radiatively coupled heat source/heater head geometries has been performed using data furnished by the developers of FPSE and GPHS. The analysis indicates that, for the 1050 K heater head configurations considered, GPHS fuel clad temperatures remain within acceptable operating limits.

Based on these results, preliminary characterizations of multihundred-watt units have been established. They indicate that, per electrical watt, the GPHS/small Stirling DIPS will be roughly equivalent to an advanced RTG in size and mass but require only a third the amount of isotope fuel.

Effort is currently underway to produce a reference conceptual design. The design addresses system level issues such as mission environment, user vehicle integration, launch and transit for a typical planetary spacecraft, in addition to basic requirements associated with launch safety, assembly and loading, ground handling and storage. The emerging design will be the basis for showing how these requirements can be met, will permit further specification of components, and enable potential users to evaluate the small Stirling DIPS as a power source.

Introduction

Within the context of today's civil space agenda there are about twenty missions presently anticipated where radioisotope power sources will be required. These include all the deep space and outer planet missions presently in the Office of Space Science and Applications (OSSA) strategic plan or proposed by the solar system exploration and space physics subcommittees (Ref. 1), and the many robotic planetary surface missions considered as precursors to later human exploration (Ref. 2). Almost all of these missions (summarized in Table I) are unmanned. From the known characterizations and the capabilities of the vehicles and spacecraft involved, none of the unmanned missions will require more than 700 watts. Dates listed for the missions are only estimates; most of them will not take place for ten years or more. Although there is an eventual requirement for multikilo-watt power to support manned missions (construction and operation of a lunar base, for example), the manned missions are not anticipated to take place until most of the unmanned missions have been completed.

The unmanned missions are remote robotic missions, to locations ranging from the lunar surface to deep space. High performance and minimum weight are desirable, but the key requirement is for reliable operation in a harsh environment, without intervention, over extended periods of time.

RTGs

The only power source presently available to meet these requirements is the radioisotope thermoelectric generator (RTG) developed for NASA by the Department of Energy (DoE). The RTG is built around the space-qualified General Purpose Heat Source (GPHS), which is also furnished by DoE. Basically an array of radiatively coupled thermoelectric (TE) cells enclosing a stack of GPHS blocks as shown in Fig. 1, this power source is the result of years of evolutionary development and flight experience. The GPHS RTGs powering the Galileo and Ulysses missions draw their design heritage and 1300 K Si Ge unicouple technology from their predecessors, the Multi-Hundred Watt (MHW) RTGs used on Pioneer and Voyager. These units are still operating after being launched more than a decade ago. Next scheduled for service on the Cassini mission, GPHS RTG may be superceded for the later missions (Solar Probe, Pluto flyby, Comet Nucleus Sample Return etc.) by Mod RTG (Ref. 3), which is the next generation in the evolutionary chain. This unit employs the new 1300 K Si/Ge/GaP multicouple, which produces higher output voltage and allows modularity and improved packaging.

RTG's have demonstrated reliability well-suited for these missions. Their thermoelectric conversion system, which has no moving parts to break or wear out, is made up of multiple series-parallel strings of redundant elements which accommodate failure of any element in the string with only partial degradation. No open circuit failures have ever been recorded; counting all the RTG powered missions flown to date, over 70 years of successful flight experience have been accumulated. For the thermoelectric converter, it translates to over 442 million operating hours, demonstrating a reliablity in service measured in decades (Ref. 4).

For missions where life and reliability are needed most, the RTG has proven to be a long lived and most reliable power source. But there is a high price to be paid. Since its thermoelectric conversion is not very efficient (typically 6 - 7 percent), an RTG needs a substantial amount of heat source in order to produce a few electrical watts. For example, a GPHS RTG producing 285 electrical watts at beginning of life (BOL) requires over 4.4 thermal kilowatts heat source. For the power system and its user, this input must ultimately be disposed of as waste heat. Waste heat is a burden on the user since it must be continuously removed, placing a substantial auxilary cooling requirement on the spacecraft during launch and transit.

The heat source is very expensive, since the low emission and long half-life plutonium isotope used in GPHS, originally available as a byproduct from nuclear weapons production, is costly to produce and remaining stocks are limited. The price paid by the government for new supplies of this material are estimated to range from $1200/gm PuO2, as quoted by the Commonwealth of Independent States (CIS) for sale from their existing stock (a byproduct of former Soviet weapons activity)(Ref 5), to $ 8000/gm PuO2 if new domestic production were initiated (Ref. 6). Each GPHS is loaded with 448 gm of active material. Counting the costs of production, encapsulation and assembly into heat source modules, the resulting mission user cost is estimated to be between $ 6000 and $18,000 per thermal watt. For an RTG, this translates to roughly $100,000 to $ 300,000 per electrical watt.

The radioisotope inventory carried by RTGs (463 Ci per electrical watt) translates to significant safety concerns (Refs. 7, 8). To a first approximation, the numerically calculated risk versus on-board inventory is a linear relationship (i.e. the more isotope carried, the greater the risk). These risks have been considered acceptable for the radioisotope powered missions carried out to date but the desire to reduce or eliminate that risk has been recognized (Ref. 9).

Dynamic Isotope Power Systems (DIPS)

Where no alternatives to isotope power are available there is a strong incentive to reduce the amount of isotope that is required. This can be accomplished by developing a power source with more efficient conversion. At present, the most efficient converters of thermal energy are dynamic heat engines. When energized by an isotope heat source, the resulting power plant is known as a dynamic isotope power system, or DIPS. A DIPS requires less isotope per delivered electrical watt because heat engines are 3-5 times more efficient than thermoelectric converters. On the other hand, they introduce the complication of moving parts.

Turbomachinery-based DIPS

Historically, DIPS development has focused on turbomachinery-based heat engine converters, primarily the closed Brayton cycle (the most well-known example of which is shown in Fig. 2). Turbomachinery is mechanically simple, with potentially high reliability, and has significant advantages of scaling to higher power levels. For multi-kWe missions such as those that were anticipated to follow in the post-Apollo era, a turbomachinery based DIPS is significantly lower in mass than the equivalent amount of RTG's. However, the turbomachinery based DIPS is not an effective competitor with RTG's for multihundred-watt missions. Application studies done by a DIPS developer for the military Boost Surveillance and Tracking Satellite (Refs. 10,11) showed that Brayton DIPS would be heavier than an ensemble of Mod RTG's whenever power requirements less than 2 kWe were considered. Later studies of this same system scaled down to multihundred-watt size and proposed as a replacement for RTG units aboard a planetary spacecraft (Ref. 12), showed that it would be heavier than Mod RTG units below 1 kWe, and heavier than GPHS RTGs when power levels below 650 We were considered (Fig. 3).

The fundamental reason for this is the poor scaling of turbomachinery to lower power levels due to fixed losses (bearing, windage, turbine tip clearance, etc). Generally speaking, turboalternator unit sizes below 500 watts are considered impractical because of scaling effects on overall converter efficiency (Fig. 4, Ref.13).

Small Stirling DIPS

The Stirling engine, particularly the more recently developed free-piston Stirling engine (FPSE) combined with a linear alternator (LA), is a better converter choice for multihundred-watt isotope power. As Fig. 5 illustrates, the FPSE/LA is quite different from the kinematic machinery developed under earlier isotope Stirling programs (Ref. 14). It is mechanically simple, typically with only two moving parts, and it is hermetically sealed. It has no oils or other organic materials inside to degrade or contaminate. Since its vibrations are essentially single frequency (moving parts reciprocate at 60 - 100 Hz) they can be easily attenuated or tuned out.

Although its invention is relatively recent (1962), the FPSE has been developed and used for a wide variety of applications accumulating a considerable background of test and operational experience at power levels ranging from 5 watts to 2 kilowatts (Ref. 15). This experience indicates potential to achieve, as an isotope engine, the high reliability that is required for decades of unattended remote operation. This is of paramount importance, since the FPSE must inevitably be compared to RTG thermoelectric converters which have accumulated years of flight experience. Some of the terrestrial FPSE units have already demonstrated service lives exceeding 10,000 hr. In test, one radioisotope heated unit achieved over 110,000 hours continuous operation (Refs. 16, 17). Other types of free piston Stirling machines, embodied as cryocoolers for several orbiting surveillance platforms, have already seen operational use in space.

The FPSE/LA is being presently developed for space power by NASA under the Civil Space Technology Initiative (CSTI) High Capacity Power program. The primary focus has been on a multikilo-watt converter for the SP-100 reactor (Ref. 18), representing a significant scale-up from the technology heritage of earlier machines which were 3 kWe or less.. Goals of the program are to demonstrate a compact, low specific mass (7 kg/kWe) converter with maximum efficiency at temperature ratios applicable to space reactor systems, and continuous service life exceeding 60,000 hrs. Thermal-to-electric conversion efficiencies of 20 percent have already been demonstrated at a temperature ratio of 2.2 .

Unlike turbomachinery, the FPSE can be advantageously scaled into the hundred-watt range of unit size and below. Published performance data from various FPSE units previously built and tested (Refs. 19 through 24), plotted in Fig. 6, demonstrate consistent performance over a unit output power range from 5 watts to 12.5 kilowatts -- roughly four orders

of magnitude. Data published by a Stirling developer (Ref. 25) indicates that multihundred-watt FPSE/LA converters having conversion efficiencies in the range 25 - 35 percent should have a specific mass within the range 10 - 12 kg/kWe at temperature ratios normally associated with dynamic isotope space power systems (2.5 to 2.8). The specific mass penalty of scaling heat engines from multi-kWe to multihundred-watt power levels still applies, but it is not as severe for FPSE/LA as for turbomachinery.

An attractive feature of the multihundred-watt FPSE/LA is its ease of thermal integration with the GPHS, which is the only space qualified isotope heat source available. Approximately 250 thermal watts each, the GPHS modules are designed for radiative coupling to a conversion system. At multihundred-watt unit size, the FPSE heater head can be heated directly by clustering the blocks around it as shown in Fig. 7, eliminating the need for a separate heat source assembly (HSA) and intermediate heat transfer loop. To maintain a 1000-1100K heater head operating temperature while keeping the fuel clad temperature within the GPHS to an acceptable limit (less than 1600K to inhibit grain growth), each individual GPHS block must have an unobstructed view of the heater head. Therefore, geometric considerations limit the largest size unit that can be integrated in this fashion to about 700 We. However, significant mass savings is achievable for these smaller units. Fig. 8 presents data from a previous comparison of small Brayton and Stirling DIPS (Ref. 26) that considered direct integration via radiative coupling. In the range (300 - 700 We) where intermediate heat exchange and transport (insulated ducts, heat pipes, pumped loops) components can be avoided, the specific power of a small Stirling DIPS can be nearly double that of a Brayton DIPS.

Since the concept was first identified (Ref. 27), the potential of combining small free-piston Stirling engines with isotope heat sources using radiative coupling has been explored (Refs. 28, 29). In these studies, various configurations of GPHS and insulation packages surrounding an opposed pair of FPSE heater heads were considered. Thermal modeling was then performed to simulate the GPHS heat source and its integration into various heat source/heater head geometries, using the analysis codes TRAYSYS and SINDA (Ref. 28). The thermal models of GPHS were correlated with data supplied by General Electric's Astro-Space Division and DOE's Mound Laboratory (two developers of the GPHS). Modeling simulated various radiatively coupled configurations, using heater head data from NASA Lewis' Stirling Technology Branch (Ref. 30). The analysis indicated the feasibility of direct integration. For heater head temperature of 1050 K, the GPHS fuel clad temperatures can be held to less than 1600K.

From the heat source/heater head geometries studied, a preliminary small Stirling dynamic isotope power system configuration emerged. Fig. 9 is an illustration showing the general layout of major components. Characterizations of the concept, which included the heat source assembly, insulation package, converter and downstream components, indicated that a multihundred-watt small Stirling DIPS should have physical dimensions similar to the DOE Mod RTG, and its performance and mass will result in a specific power of 7- 8 W/kG. As the summary comparison presented in Table 2 shows, however, small Stirling DIPS will require only one third the radioisotope.

The characterization has so far been preliminary. Efforts are now underway to improve the system definition and produce a conceptual design. This design shall have sufficient level of detail to address not only electrical power production from a GPHS, but also the basic spacecraft isotope power system critical requirements of safety during launch and transit, re-entry, installation onto user vehicle and delivery of useable power to the spacecraft bus. Also, the design will detail requirements encompassing continuous operation within the mission environment, life and reliability, and compatibility with on board users including vibration and electromagnetic disturbances. Design considerations peculiar to power systems that incorporate nuclear materials are also being addressed. These include loading of GPHS modules into the unit, its subsequent assembly, ground handling and storage, and attachment to the vehicle prior to launch. The design definition will show how each requirement is met, and establish subsystem and component requirements leading to critical hardware definition. Subsystems and components include the heat source/heater head assembly, FPSE/LA converters, cold end rejection loop and radiator, and electrical power conditioning and controls.

To ensure that the design addresses major concerns from a user standpoint, the Jet Propulsion Laboratory (JPL) Spacecraft Power Systems section (engineering matrix support for JPL's deep space and plantetary flight projects) is furnishing mission and user vehicle requirements. Currently the reference mission is Cassini, using the Mariner Mk II spacecraft as the reference vehicle.

Present efforts at NASA Lewis Research Center are focussing on engine configuration and the thermal, mechanical and electrical integration of the FPSE/LA to other subsystems. Design assistance for the integrated heat source/heater head assembly containing GPHS modules is being provided by Mound.

The design shall provide not only a credible estimate of hardware physical attributes but also a preliminary assessment of life and reliability that could be expected. This will enable potential users to evaluate the small Stirling DIPS as a low cost alternative to RTG's.

Conclusion

For the forseeable future, the most likely missions for radioisotope power sources are long duration robotic missions at power levels in the multihundred-watt range. RTG's are normally considered for these missions but they require large amounts of isotope heat source which is hard to obtain, hazardous, and expensive. Because a dynamic system requires significantly less isotope to produce power, it could reduce the costs, and possibly the risks, to the mission. It has to be sufficiently small, light, and reliable, however, in order to replace the RTG.

It is possible to build a multihundred-watt DIPS by combining GPHS with the free-piston space Stirling engine technology now being developed. The FPSE/LA, which can be built as a practical converter in the hundred-watt unit size, is directly integrated with the GPHS heat source through radiative coupling to the FPSE heater head, thus avoiding intermediate heat transfer devices, and minimizing system mass. Thermal analysis has shown the concept to be feasible, and preliminary system characterizations show it to be attractive. On a per electrical watt basis it is equivalent in size and weight to the RTG, but requires only one third the radioisotope. If long term reliability of the small free-piston Stirling space engine can be demonstrated, small Stirling DIPS can provide a low cost alternative to RTG's for these missions.

Because FPSE/LA technology appears to have potential to meet the multihundred-watt robotic mission requirements, and because the potential benefits are too attractive to ignore, efforts are now underway to further develop and critically examine the small Stirling DIPS concept.

REFERENCES

1.) R. Boain, "Solar System Exploration and Space Physics Missions Update", Proc. 2nd JPL Radioisotope Power Systems Requirements Workshop, Arcadia CA June 1991

2.) D. Petri, R. Cataldo and J. Bozek, "Power System Requirements and Definition for Lunar and Mars Outposts", Proc. 25th IECEC, Reno NV August 1990

3.) R. Hartmann, "Modular RTG Technology Status", proc. 25th IECEC, Reno NV, August 1990

4.) E. Skrabek, "Performance of Radioisotope Thermoelectric Generators in Space", Proc. 7th Symposium on Space Nuclear Power Systems, Albuquerque NM, January 1990

5.) Correspondence to Deputy Director, NASA Solar System Exploration Division dated May 17 1991, and to Deputy Assistant Secretary for Nuclear Energy USDoE dated 09 September 1991 from Rasor Associates Inc./Concord Trading Co./Mayak/Tenex.

6.) Reported by U.S. Department of Energy Office of Space/Defense Energy Projects at Prospector II Radioisotope Power Sources Workshop, Park City Utah, March 22 - 25, 1992

7.) R. Englehart, "Mechanics of Space Nuclear Safety", Proc. First Symposium on Space Nuclear Power Systems, Albuquerque NM, January 1984

8.) G. Bennet et al, "Development and Implementation of a Space Nuclear Safety Program", Proc. 4th Symposium on Space Nuclear Power Systems, Albuquerque NM, January 1987

9.) S. Aftergood, "A Critical View of Space Nuclear Power", Proc. 5th Symposium on Space Nuclear Power Systems, Albuquerque NM, January 1988

10.) G. Bennett, J. Janzen, J. Lombardo and A. Mehner, "The Dynamic Isotope Power System Technology Program", Proc. 23rd IECEC, Denver CO. August 1988

11.) R. Brandewie, "Lockheed Missiles and Space Company BSTS PowerSystem Definition Study", Rev. 1, RI/RD86-188, Rocketdyne Div., Rockwell International Corporation, Canoga Park CA July 1, 1986

12.) W. Determan, D. Chung, A. Stadnik and R. Johnson, "Low Power DIPS for Interplanetary Missions", Proc. 25th IECEC, Reno NV, August 1990

13.) R. Johnson and A. Stadnik, "Dynamic Isotope Power Systems (DIPS) for Space Exploration - Technical Information", Rockwell International Rocketdyne Division document BD 90-27, prepared for USDOE under Contract No. DE-AC03-88NE32129, Canoga Park, CA, May 1990

14.) D. Lehrfeld and W. Richards, "Stirling Engine Power System Development and Test Results", Proc. 15th IECEC, Seattle WA, August 1980

15.) B. Ross and J. Dudenhoeffer, "Stirling Machine Operating Experience" Proc. 26th IECEC, Boston MA August 1991

16.) E. Cooke-Yarborough,"Small Stirling-Cycle Power Sources in Marine Applications", OCEANS 80 International Conference on Ocean Engineering,

17.) E. Cooke-Yarborough, Personal Communication dated 17 Sept. 1990

18.) J. Dudenhoeffer and J. Winter, "Status of NASA's Stirling Space Power Converter Program", Proc. 26th IECEC, Boston MA, August 1991

19.) M.A. White, et al,"Fully Implantable Stirling Engine for Artificial Heart Power", Proc. 17th IECEC, Los Angeles CA, August 1982

20.) D. Berchowitz, "The Development of a 1 kW Electrical Output Free Piston Stirling Engine Alternator Unit", Proc. 18th IECEC, Orlando FL, August 1983

21.) R. Berggren and T. Moynihan, "1 kilowatt Free Piston Stirling Engine Power and Performance Tests", ANL-CT-83-7 Part 1, Argonne National Labs, June 1983

22.) J. Schreiber, S. Geng and G. Lorenz, "RE-1000 Free Piston Stirling Engine Sensitivity Test Results", NASA TM 88846, October 1986

23.) N. Lane, D. Berchowitz, D. Shade and A. Karandikar, "Development of a High Frequency Stirling Engine-Powered 3 kWe Generator Set", Proc. 24th IECEC, Washington DC, August 1989

24.) J. Cairelli and S. Geng, "Results from Baseline Tests of the SPRE I and Comparison with Code Model Predictions", Proc. 24th IECEC, Washington DC, August 1989

25.) G. Dochat and M. Dhar, "Free Piston Stirling Engine System Considerations for Various Space Power Applications", Proc. 8th Symposium on Space Nuclear Power Systems, Albuquerque NM, January 1991

26.) D. Bents et al "Comparison of Dynamic Isotope Power Systems for Distributed Planetary Surface Applications", Proc. 8th Symposium on Space Nuclear Power Systems, Albuquerque NM, January 1991

27.) D. Bents, "Preliminary Assessment of Rover Power Systems for the Mars Rover Sample Return Mission", Space Power Vol 8, No 3 1989

28.) T. McComas and E. Dugan, "Thermal Analysis of a Conceptual Design for a 250 We GPHS/FPSE Power System", Proc. 26th IECEC, Boston, MA August 1991

29.) D. Bents, "Small Stirling Dynamic Isotope Power System for Multihundred-watt Robotic Missions", Proc. International Pacific Aerospace Conference, Gifu Japan, October 1991

30.) Private communications J. Screiber and S. Geng to T. McComas, D. Bents and C. Withrow

Radioisotope Missions

MISSIONS THAT REQUIRE RADIOISOTOPE POWER SOURCES

Missions in the Code S Strategic Plan	PROPOSED LAUNCH DATE	MISSION DURATION	Estimated EOM Power Level
CASSINI	1998	10.5 yrs.	480 w
SOLAR PROBE	post 2000	8 yrs.	500 w
Solar System Exploration (SL) Missions			
PLUTO FLYBY	1998	14 - 16 yrs.	700 w
NEPTUNE ORBITER	2002	20 yrs.	30 w
MARS ROVER SAMPLE RETURN	2001	4 yrs.	500 w
SOLAR PROBE	2001	8 yrs.	337 w
URANUS ORBITER	2007 - 11	14 - 16 yrs.	700 w
COMET NUCLEUS SAMPLE RETURN	20007 - 11	8 yrs.	500 w
Space Physics (SS) Missions			
INTERSTELLAR PROBE	circa 2010	20 - 25 yrs.	200 - 500 w
POLAR HELIOSPHERIC PROBE	post 2010	35 yrs.	200 - 500 w
SEI Precursor Missions			
LUNAR SITE ROVER (2 mission)	1997	1 - 2 yrs.	100 - 300 w
MARS ENVIRONMENT SURVEY (MESUR)	1998	5 yrs.	15 w
LUNAR SURFACE TELESCOPE PACKAGE	1998	5 yrs.	200 - 500 w
LUNAR COMM. NETWORK (4 missions)	1998 and 1999	> 10 yrs.	100 w
MARS ROVER SAMPLE RETURN	post 2000	4 yrs.	500 w
MARS SITE SURVEY ROVER	post 2000	5 yrs.	400 w
SEI Manned Missions			
UNPRESSURIZED LUNAR ROVER	post 2000	960 hrs.	2 - 5 kW
PRESSURIZED LUNAR ROVER	post 2000	96 hrs.	12 kW
LEV SERVICER	post 2000	1 yr.	10 kW

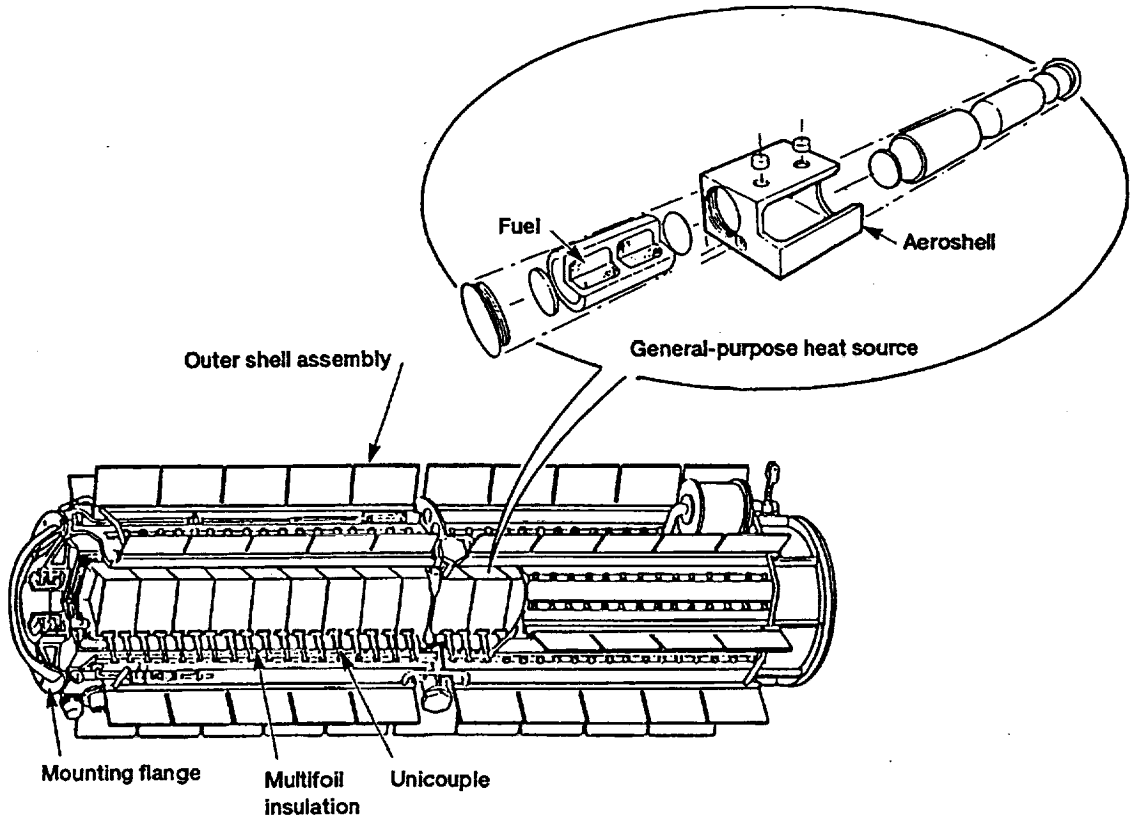

Figure 1.—General-purpose heat source - RTG.

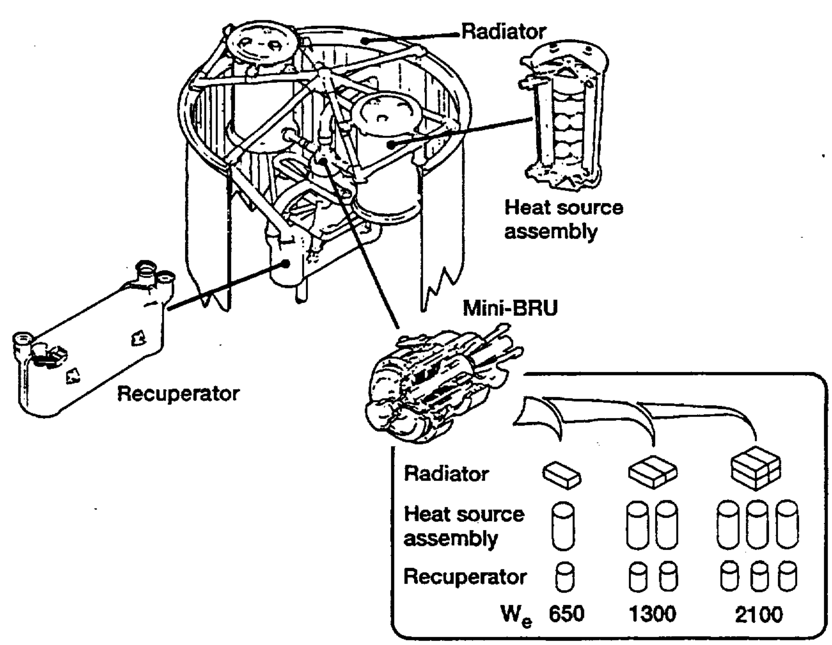

Figure 2.—Brayton isotope power system (BIPS).

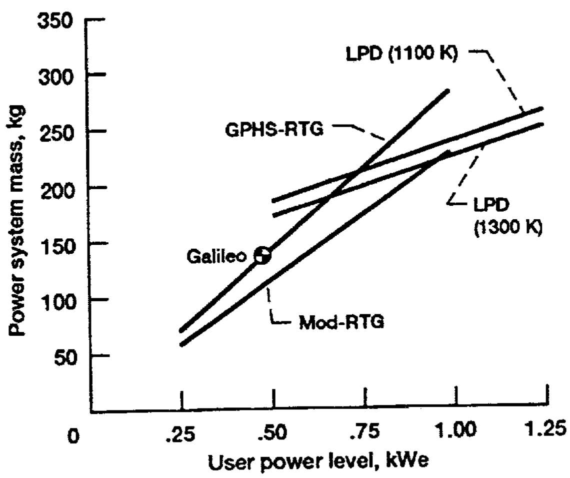

Figure 3.—Low-power DIPS versus RTG system masses (from ref. 12).

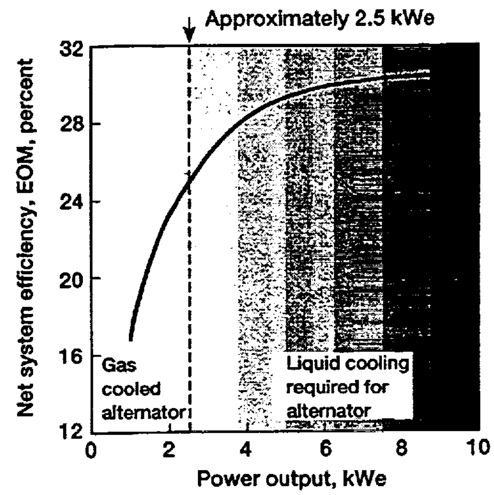

Figure 4.—DIPS efficiency characteristics; 1300 K turbine inlet temperature systems. Bearing, windage, thermal, electrical losses represent larger fraction at lower power. Smaller diameters decrease aerodynamic efficiencies at low power. (From Ref. 13.)

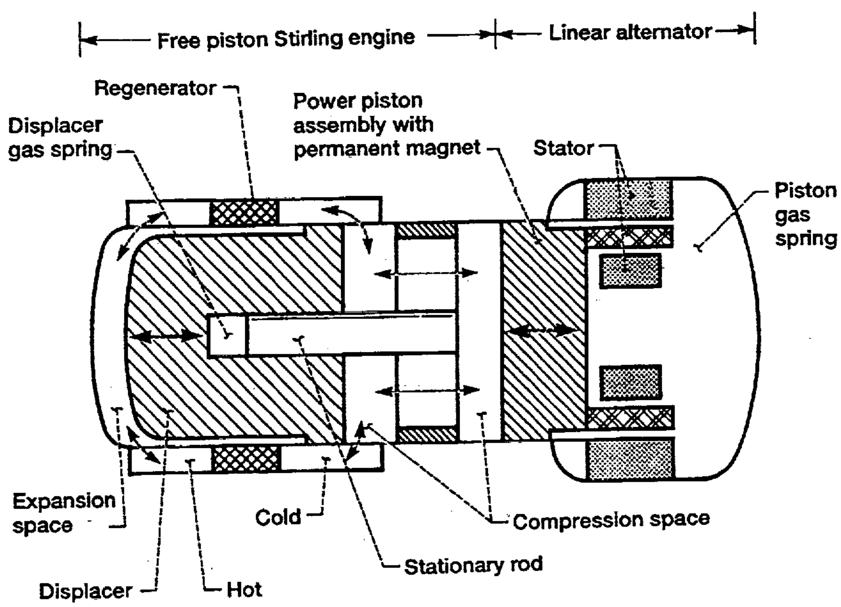

Figure 5.—Free piston Stirling engine/linear alternator.

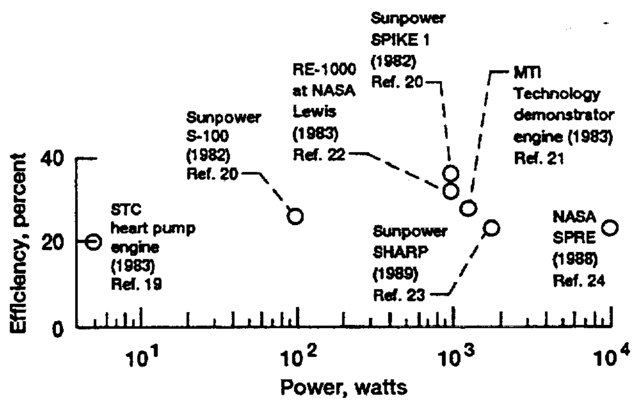

Figure 6.—Measured performance of selected free piston Stirling engines of various unit sizes.

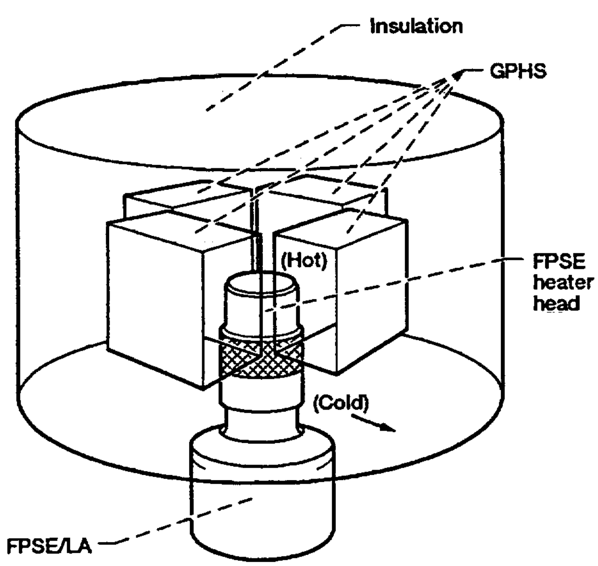

Figure 7.—Direct heat source/heater head integration.

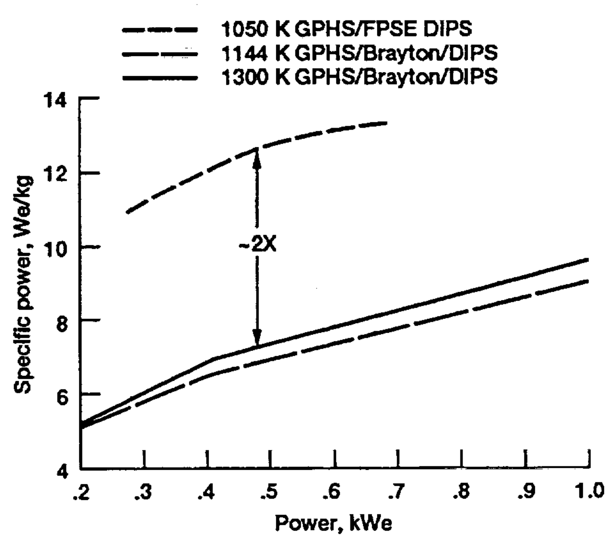

Figure 8.—Multihundred watt unit comparison. Stirling DIPS (direct integration) versus mass optimized Brayton DIPS (single PCU). (From Ref. 26.)

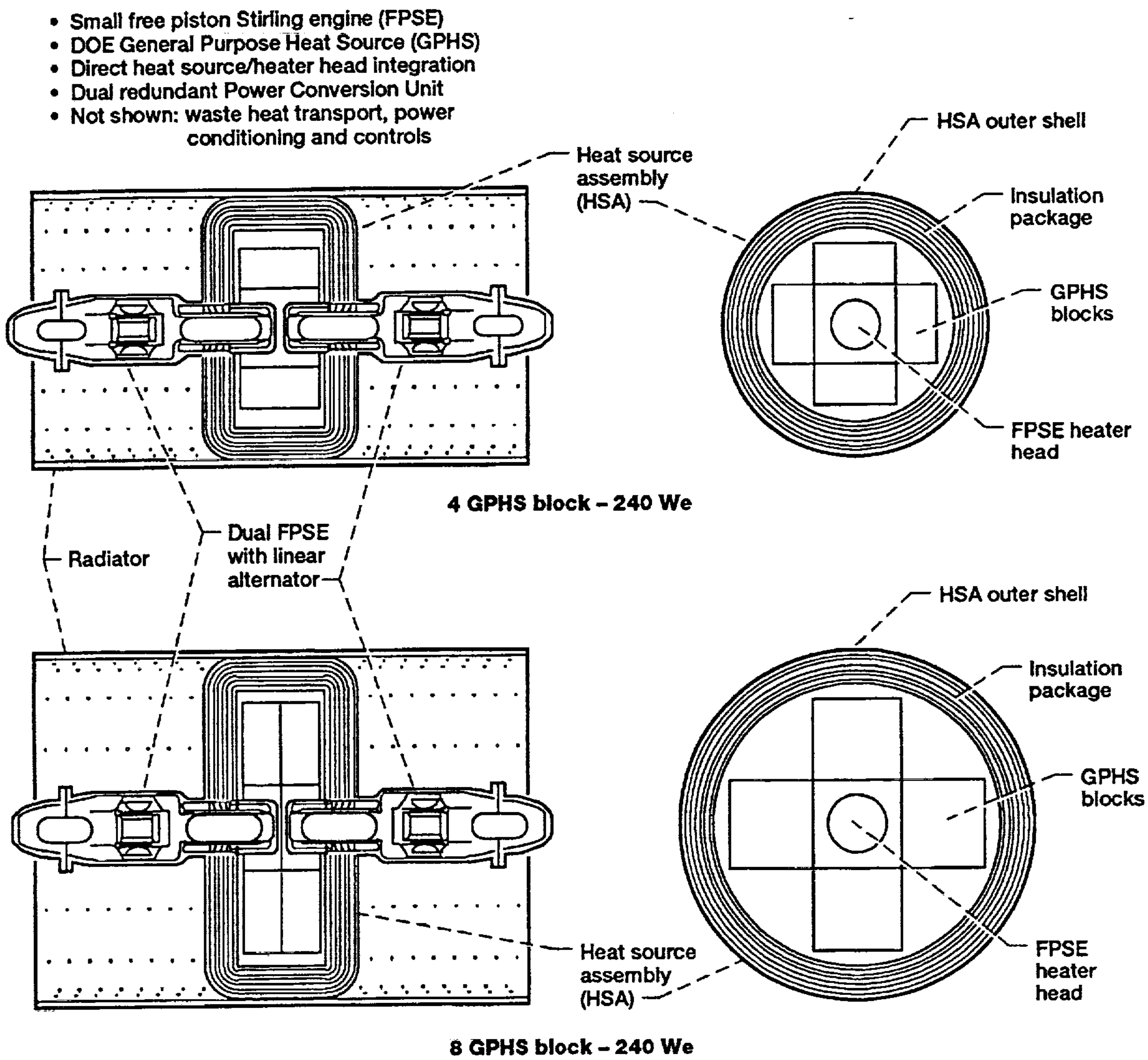

Figure 9.—Multihundred-watt GPHS/FPSE/DIPS.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1992	Technical Memorandum

4. TITLE AND SUBTITLE

Small Stirling Dynamic Isotope Power System for Robotic Space Missions

5. FUNDING NUMBERS

WU-596-13-11

6. AUTHOR(S)

D.J. Bents

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E-7215

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-105785

11. SUPPLEMENTARY NOTES

Prepared for Nuclear Technologies for Space Exploration sponsored by the American Nuclear Society, Jackson Hole, Wyoming, August 16–19, 1992. Responsible person, D.J. Bents, NASA Lewis Research Center, (216) 433–6135.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 20

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Design of a multihundred-watt Dynamic Isotope Power System (DIPS) based on the U.S. Department of Energy (DOE) General Purpose Heat Source (GPHS) and small (multihundred-watt) free-piston Stirling engine (FPSE) is being pursued as a potential lower cost alternative to radioisotope thermoelectric generators (RTGs). The design is targeted at the power needs of future unmanned deep space and planetary surface exploration missions ranging from scientific probes to Space Exploration Initiative precursor missions. Power level for these missions is less than a kilowatt. The incentive for any dynamic system is that it can save fuel, reducing cost and radiological hazard. Unlike DIPS based on turbomachinery conversion (e.g. Brayton), this small Stirling DIPS can be advantageously scaled to multihundred-watt unit size while preserving size and mass competitiveness with RTGs. Stirling conversion extends the competitive range for dynamic systems down to a few hundred watts – a power level not previously considered for dynamic systems. The challenge for Stirling conversion will be to demonstrate reliability and life similar to RTG experience. Since the competitive potential of FPSE as an isotope converter was first identified, work has focused on feasibility of directly integrating GPHS with the Stirling heater head. Thermal modeling of various radiatively coupled heat source/heater head geometries has been performed using data furnished by the developers of FPSE and GPHS. The analysis indicates that, for the 1050 K heater head configurations considered, GPHS fuel clad temperatures remain within acceptable operating limits. Based on these results, preliminary characterizations of multihundred-watt units have been established. They indicate that, per electrical watt, the GPHS/small Stirling DIPS will be roughly equivalent to an advanced RTG in size and mass but require only a third the amount of isotope fuel. Effort is currently underway to produce a reference conceptual design. The design addresses system level issues such as mission environment, user vehicle integration, launch and transit for a typical planetary spacecraft, in addition to basic requirements associated with launch safety, assembly and loading ground handling and storage. The emerging design will be the basis for showing how these requirements can be met, will permit further specification of components, and enable potential users to evaluate the small Stirling DIPS as a power source.

14. SUBJECT TERMS

Dynamic isotope power systems; Free piston Stirling engines; General purpose heat source

15. NUMBER OF PAGES

18

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	